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Enlarged Ship Concept Applied to RORO Cargo/Passenger Vessel

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Developments in Marine Technology, 11

Practical Design of Ships and Mobile Units

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MARIN	Maritime Research Institute Netherlands
KIvI	Royal Institute of Engineers in The Netherlands
KM	Royal Netherlands Navy
NVTS	Netherlands Association of Maritime Engineers
TNO	Netherlands Organization for Applied Research
TU Delft	Delft University of Technology

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The Local Organizing Committee organized the Symposium under supervision of the PRADS's Standing Committee. The Symposium benefited from the generous support of a number of Sponsors. These, together with the membership of the committees, are listed in the following.

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PREFACE

These Proceedings contain the papers presented at the 7th International Symposium on Practical Design of Ships and Mobil Units. The Symposium was held at the CONGRESS CENTRE in The Hague, The Netherlands, on 20 - 25 September 1998.

The overall aim of PRADS Conferences is to advance the design of ships and mobile marine structures through the exchange of knowledge and the promotion of discussions on relevant topics in the fields of naval architecture and marine and offshore engineering. Greater international co-operation of this kind can help improve design and production methods and so increase the efficiency, economy and safety of ships and mobile units. Previous symposia have been held in Tokyo ('77 and '83), Seoul ('83 and '95), Trondheim ('87), Varna ('89) and Newcastle ('92).

The main themes of this Symposium are Design Synthesis, Production, Ship Hydromechanics, Ship Structures and Materials and Offshore Engineering.

Proposals for over two hundred papers have been received for PRADS '98 from 25 countries, and 126 have been accepted for presentation at the Conference. Given the high quality of the proposed papers, it has been a difficult task for the Local Organising Committee to make a proper balanced selection.

Some topics which attracted many papers were Design Loads, Design for Ultimate Strength, Impact of Safety and Environment, Grounding and Collision, Resistance and Flow, Seakeeping, Fatigue Considerations and Propulsor and Propulsion Systems. The great current interest in these topics and the high quality of the papers guarantee a successful Conference.

The success of PRADS '98 depends on the great contributions of the participants with a special acknowledgement to the authors.

We as Local Organizing Committee have done our utmost to create the proper atmosphere for an interesting and enjoyable conference.

M.W.C. Oosterveld and S.G. Tan

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Practical Design of Ships and Mobile Units
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Enlarged Ship Concept Applied to RORO Cargo/Passenger Vessel

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The "Enlarged Ship Concept" (ESC) was successfully applied to a fast semi-planing 26 m. patrol boat by Keuning and Pinkster [1,2]. Their results showed a significant performance improvement both in a technical and economical sense. In order to investigate if ESC may also render a similarly successful design strategy for a RORO/Passenger vessel which is representative for present services in the UK-West Europe route, the underlying study was carried out. The outcome of this study is that some important results are quite the opposite to those of the patrol boat; this is mainly due to the large difference in vessel types and Froude numbers involved. Within a given payload weight, the larger RORO vessels have more cargo carrying capacity in terms of trailers; in other words, the enlarged vessels can carry more trailers if the trailers are not fully laden. Furthermore, the larger vessels are less vulnerable in damaged condition since the lower hold is not used for cargo and can therefore freely be optimally subdivided. Also advantageous is the fact that the draft decreases as the length increases which results in a higher freeboard for the larger vessels. Summarising, it appears that application of ESC to this type of vessel creates more income possibilities for the shipowners and a much safer vessel, but it produces a more expensive ship to buy and exploit.

1. INTRODUCTION

In 1995 Keuning and Pinkster [1] explored the so-called "Enlarged Ship Concept" (ESC) by applying this to a fast 25 knot, semi-planing, 26 m. patrol boat. The Froude number was, based on vessel length, equal to 0.81. The main driver behind this application was the fact that a monohull sailing at high forward speed in head waves may incur unacceptably high vertical accelerations which may hamper the safe operability of the craft. In essence, they improved the seakeeping behaviour and decreased the resistance of the fast patrol vessel by increasing the length in steps of 25% and 50% and so increased also the length to beam ratio, reduced the running trim under speed and improved the general layout of the ship. Their work carried concerned three design concepts, namely a base boat with two enlarged ship configurations. The key to the ESC is that deadweight, i.e. payload, fuel and stores as well as vessel speed remain constant and equal to that of the base boat. The most important results from this study showed, on the one hand, a 38% marked improvement regarding a decrease in vertical acceleration in the wheelhouse in head seas and a 40 % decrease in required propulsion power in calm water at a speed of 25 knots; on the other hand the maximum purchasing price of the largest design alternative was estimated to be only 6% higher than that of the basic 26 m. patrol boat.

In 1997 Keuning and Pinkster [2] presented further research on the ESC topic, extensive model testing related to vessel resistance and motions were carried out and subsequent results were described in detail. This second study confirmed the results of the first study and favoured, once again, the Enlarged Ship Concept. In the meantime, the results from these studies have been applied to a number of new buildings of fast patrol boats in The Netherlands.

Now, the question arises, " Can the ESC also be successfully applied to the common work horse of the seas, the ordinary marine freighter? ".

In the present paper, an attempt was made to answer this question by applying the same ESC to a full time "freight carrying" vessel being a RORO/Passenger Vessel representative for present services in the UK-West Europe route. The base vessel of 157 m. length was lengthened by respectively 25 and 50 per cent, while deadweight and speed remained constant. The consequences with regard to vessel mass, stability and trim, cargo hold configuration, propulsion power, freeboard, net tonnage and building costs were evaluated. On the operability side, seakeeping performance as well as operability were also assessed. Finally costs were determined for the base ship as well as for the two ESC alternatives.

2. THE "BASE SHIP"

The base vessel used for the study was m.v. NORBANK owned by North Sea Ferries and built in 1993 by the Dutch shipyard Van der Giessen-de Noord. This vessel is a well proven design and has been described in more detail in [3]. The vessels main particulars are given in table 1. All design and functional requirements, such as speed, payload, accommodations etc., for the Enlarged Ship Concepts were based on and kept identical to those of this base ship. Relevant design information regarding hull form, stability and trim, masses, building costs etc. of the basic monohull were kindly made especially available to the authors for the work carried out here.

3. THE "ENLARGED SHIP" DESIGNS

To yield the Enlarged Ship Concepts the basic 157.65 m. ship, forthwith designated ESC-0, was enlarged in length only. Two such designs alternatives, ESC-1 and ESC-2, were made, having a length of respectively 197.06 m. and 235.85 m. . The enlarged alternatives are shown in Figure 1 along with the base ship whereas the main design particulars for all designs are given in Table 1.

With regard to engineering of all these alternatives the starting point was relative data related to the base ship. The increase in length was, in both cases, created by inserting a parallel midship section with respective lengths of 25% Lpp and 50% Lpp. In this way the original body plan remained unchanged in both the forward and aft part of all design alternatives; thus keeping the good lines of flow to the propellers and along the bow. Subsequently hydrostatic particulars were computed for the new body plans.

The increase in structural masses of all alternatives was also computed via the original mass data which was augmented with extra frames and hull plating, taking into account the relevant positions of the centres of gravity of all components of the designs. Also, since an increase in vertical bending moment may be expected to be approximately proportional to the square of the length ratio for the enlarged vessels, i.e. 1.55 and 2.25, an extra allowance has been made for an increase in steel mass of the parallel midship sections of respectively 20% and 45% for the ESC-1 and ESC-2 alternatives. This extra steel, in the form of deckplating, is thought to be placed in the upper deck of the midship section as it is then effectively positioned furthermost from the neutral line and thereby reduce the bending stresses to an equal level of the base ship. The deadweight of the enlarged vessels was placed in such a manner that no trim angles occurred.

The resistance and propulsion calculations were also made for each alternative.

Since the idea behind the Enlarged Ship Concept is equal payload for all possible alternatives, similar main dimensions such as breadth, depth etc., the vessel configuration (i.e. also position of accommodations, wheelhouse etc. with respect to the bow) remains unchanged to that of the basic ship for each design alternative concerned. Consequently, the forward position of the wheelhouse has a distinctive disadvantage with regard to ship motions.

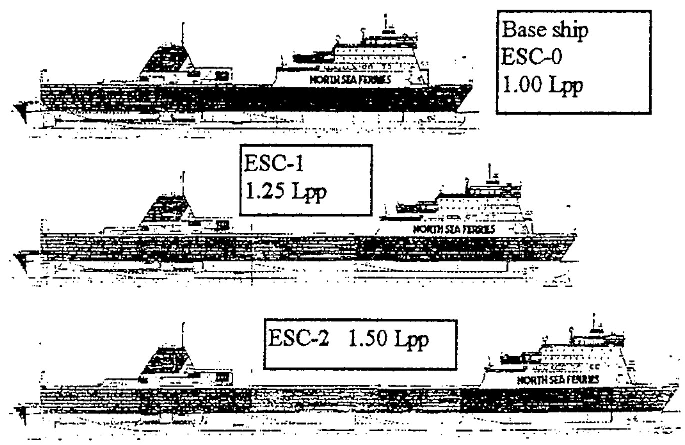

Figure 1. Side elevation of base ship and ESC designs.

4. SHIP RESISTANCE

The still water resistance for all three designs was calculated using the method of Holtrop and Mennen [4] for a range of speeds up to the design speed of 22 knots. This speed corresponds to a Froude number of

).29 for the base ship. Figure 2-a shows the still water resistance coefficients (C_t) of the three ships, subdivided into frictional (C_f) and residual (C_r) parts. From this figure it appears that, when comparing with the base ship ESC-0 at a speed of 22 knots, ESC-1 has a decrease in resistance coefficient of about 15 per cent while ESC-2 shows 10 per cent decrease only. However, this favourable effect becomes completely lost due to an increase of the wetted surface of the hull with 20 and 45 per cent respectively. As a result of this the total still water resistance will increase with approximately 5 and 30 per cent for ESC-1 and ESC-2, respectively; see Figure 2-b.

An important conclusion regarding still waterresistance is that, when the Enlarged Ship Concept is applied to these ships, there is not a similar profit to be gained as for the fast semi-planing patrol boats from [1] with up to 40% reduction in still water resistance. This finding may be attributed to the relative low Froude numbers (0.29 for ESC-0) compared to those of the patrol boats (0.81 for the base ship.

Since the vessel resistance is known for m.v. NORBANK (ESC-0), a ratio between actual and computed resistance was determined. This correction coefficient was then applied to the computed resistance of the larger vessels for establishing the required propulsive power.

Since the topic investigated in this paper deals with large seagoing vessels, ship motions are calculated at 20 and 15 knots. When assuming that the still water resistance is proportional to at least the square of the ship speed and using calculated data on added resistance in seaway, a sustained sea speed in rough weather dropped from 22 to 15 knots would expect to be an acceptable average.

Table 1
Main particulars of the base ship and alternative ESC designs

Parameter	Dim.	ESC-0	ESC-1	ESC-2
Loa	m	166.77	206.18	244.97
Lpp	m	157.65	197.06	235.85
Bmld	m	23.40	23.40	23.40
T	m	5.80	4.97	4.50
KB	m	3.26	2.69	2.36
BM	m	9.01	10.25	11.35
KG	m	10.42	10.83	10.87
MG	m	1.85	2.11	2.84
Cb	[-]	0.61	0.64	0.66
Depth to main deck	m	8.60	8.60	8.60
Depth to upperdeck	m	14.40	14.40	14.40
Lightshipweight	t	7417	9126	11176
Deadweight	t	6020	6020	6020
Displacement	t	13437	15146	17196
Speed	kn	22	22	22
Propulsion power	kW	24480	25700	33500
Passengers	no	120	120	120
Lane length upperdeck	m	930	1190	1450
Lane length maindeck	m	910	1170	1430
Lane length hold	m	200	0	0
Trailer capacity @ 40 t	no	156	165	165
Water ballast	t	234	0	0
Gross tonnage	GT	17464	21452	25396
Net tonnage	NT	5239	6436	7619
k_{xx}/B	[-]	0.43	0.43	0.43
k_{yy}/Lpp	[-]	0.29	0.29	0.29
k_{zz}/Lpp	[-]	0.29	0.29	0.29

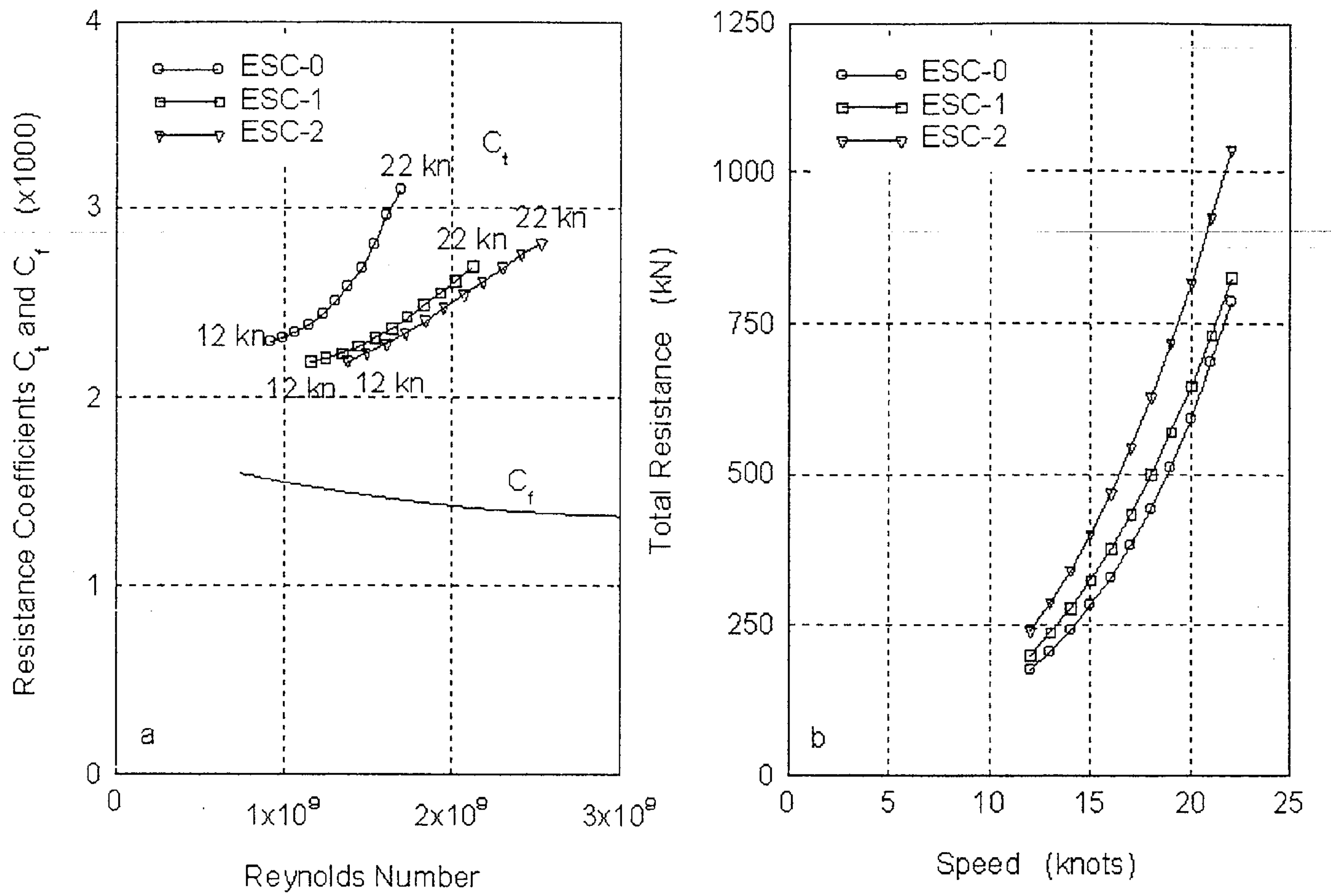

Figure 2. Results of resistance calculations.

5. SHIP MOTIONS

The vessel motions were calculated using the linear strip theory program SEAWAY of the Delft Ship Hydromechanics Laboratory [5]. These calculations were carried out in Beaufort 7 to 12, at wave directions ranging from head to following seas. The energy distribution of the irregular waves in the considered coastal areas was described by uni-directional JONSWAP wave spectra. According to Hasselmann [6], this wave energy distribution is a favourable choice for a fetch limited seaway. A commonly used relationship between period, wave height and Beaufort number was utilised. The long term probability on exceeding a certain sea state was obtained from Global Wave Statistics whereas the limiting criteria of ship motions were obtained from Karppinen [7].

In order to assess the ship's radii of gyration, an analysis has been made of the mass distribution over the length of the various designs.

Figure 3-a shows the vertical significant acceleration amplitude at the bridge in head seas as a function of the Beaufort scale with an acceleration criterion of 0.3 g. At both speeds course can be maintained by ESC-0 in sea states up to Beaufort 8, which will be exceeded during about 2 percent of the year.

However not unexpected, the two enlarged ships ESC-1 and ESC-2 can maintain their course up to Beaufort 9 and 10 respectively. Figure 3-b shows the probability on slamming in head waves, defined by a relative vertical velocity criterion at the bow. Using a slamming criterion of 2 per cent, all ships can maintain their course up to Beaufort 8. The effect of ship size and forward speed on slamming appears to be relatively small.

Figure 3-c shows the horizontal significant acceleration amplitude at the bridge in beam seas as a function of the Beaufort scale with an acceleration criterion of 0.24 g. The effect of forward ship speed is negligible. Course can be maintained by ESC-0 and ESC-1 in sea states up to Beaufort 9, which will be exceeded during less than 1 percent of the year. However, the operability of ESC-2 is limited to

Beaufort 8, which sea state will be exceeded during about 2 per cent of the year.

Figure 3-d shows the significant roll amplitude in beam seas as a function of the Beaufort scale with a roll criterion of 12 degrees. The effect of forward ship speed is negligible. The ships heading can be maintained by ESC-0 and ESC-1 in sea states up to above Beaufort 11, but the operability of ESC-2 is limited to Beaufort 10. However, the probability of occurrence of this sea state is only 0.2 per cent.

From these calculations it was concluded that the overall motional behaviour of ESC-1 is comparable with that of ESC-0. The behaviour of ESC-2 is somewhat better in head seas and somewhat worser in beam seas when compared to the base ship.

The largest impact of all may be found when evaluating bending moments.

Figure 4-a shows the distribution of the vertical bending moment (M_y) in still water over the ship length. Compared to ESC-0, for the enlarged vessels these moments have been increased by approximately 40 and 60 per cent. According to the classical theory of a uniformly loaded elastic beam, simply supported at both ends, the vertical bending moment increases with the square of the length of the beam. When considering a vessel positioned in a longitudinal (quasi static) wave with a length equal to that of the ship and the wave crests at both ends, one can expect a similar increase in vertical bending moments for the enlarged ships (55 and 125 per cent respectively). This simple approach to the problem is confirmed by dynamic calculations of the vertical bending moment (M_y) in head seas (rendering increases of about 50 and 150 per cent respectively); see Figure 4-c.

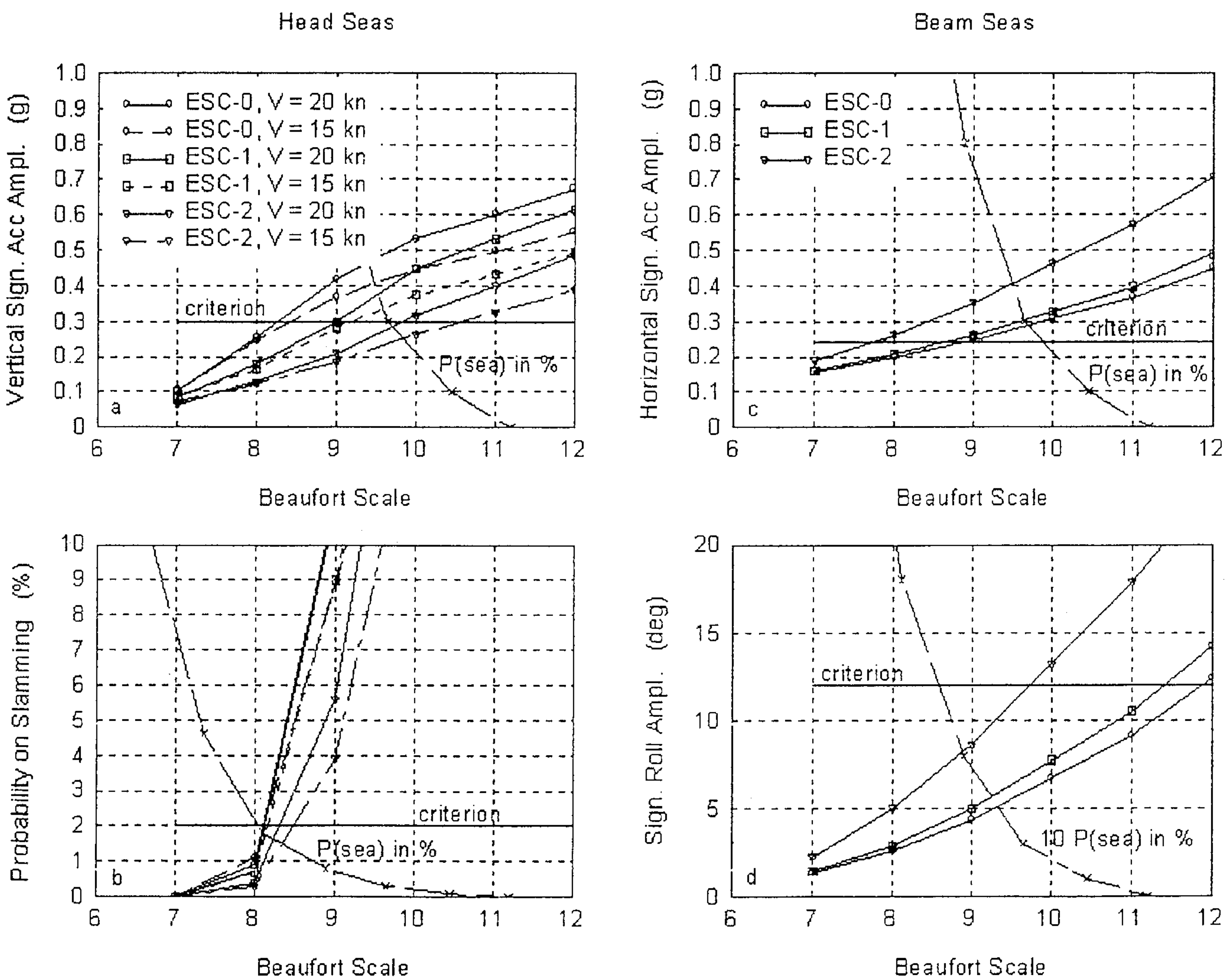

Figure 3. Motional behaviour of ESC's in seaway.

The largest horizontal bending moments (M_z) and torsional moments (M_x) have been found in bow-quartering waves (μ=120°);see figures 4-b and 4-d for the corresponding significant amplitudes. The stresses caused by the torsional moments (M_x) do not play an important role because of the closed character of the midship section. As the lateral bending moments (M_z) are much smaller than the vertical bending moments (M_y) the latter is dominant for this shiptype. Considering similar main frame scantlings for all three designs, the result would be an increase in bending stresses in the outer fibres of the larger vessels in the order of 55 and 125 per cent respectively. To deal with this increase, an increase in scantling mass for the enlarged part of the vessels has been allowed for about 20 and 45 per cent respectively. Since this extra mass is mainly required in the midship section, the mass distribution is assumed to have the form of a triangle with its base length equal to the length of the enlarged part and its top in the middle of it. This extra mass is distributed as such, in the upper deck of the vessels, having thereby the most optimum effect in reducing bending stresses. As the ends of the enlarged part are the original midship section, here lower scantling dimensions can now be expected due to a distance from amidships. However, this will be, more or less completely, overruled by the effect of an increase of the ship length.

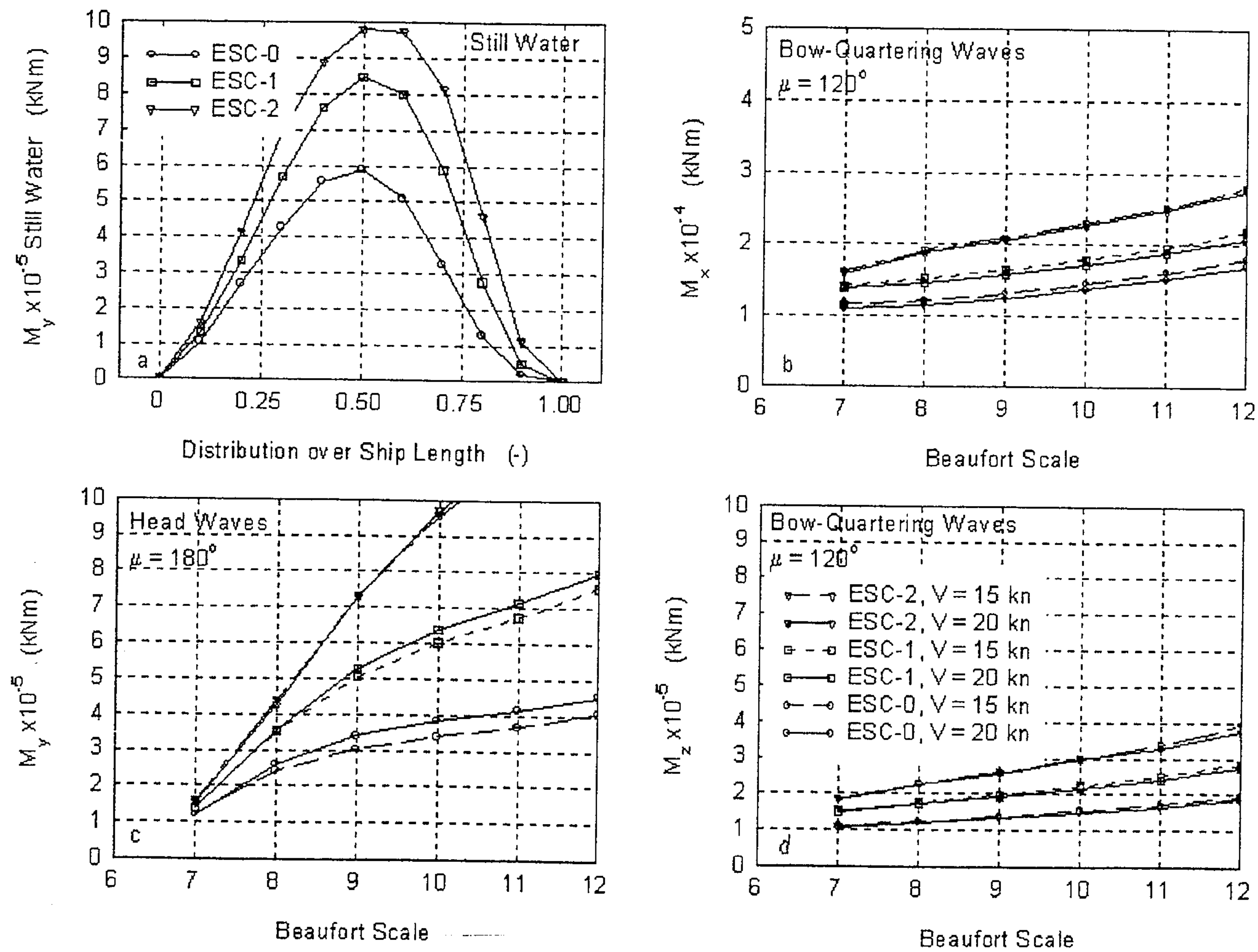

Figure 4. Torsional, vertical and horizontal moments.

6. ECONOMIC EVALUATION

In order to make an economical evaluation the building costs of the different design alternatives were estimated using the original building costs of the base ship (of which all costs components were known) and correcting this for changes in steel mass of the hull and extra painting costs (i.e. cleaning, preparation and painting) and also for extra machinery costs. The differences in building costs

are indexed with regard to the ESC-0 in Table 2. Note the increase in building costs of about 10% for ESC-1 and 28% for ESC-2.
The operational costs of the design alternatives are considered for a scenario of a twenty year economic life of the ship, sailing 18 hours per day at 22 knots, 7 days a week for 48 weeks per year and crewed by 30 persons (3 shifts per 24 hours). The differences in operational costs are indexed with regard to the ESC-0 in Table 2. Note the relatively high increase in operational costs of about 8% for design alternative ESC-1. This increase is even more dramatic in the case of the ESC-2 design alternative (i.e. 18%).
The transport efficiency (TE) - defined, in this particular case as: number of trailers times service speed in m/s over installed power in kW - has been calculated for the three designs. The differences in TE are indexed with regard to ESC-0 in Table 2. When dealing with trailers of 40 ton: an increase in TE of only 1% for ESC-1 is gained, while a decrease of about 20% is calculated for ESC-2. However, when allowing less than 40 ton per trailer and utilising the available trailer space on both D and E decks, the increase of TE becomes 17 and 13 per cent respectively.
Applying the enlarged ship concept to such a RORO vessel as presented in this paper, renders an improvement in concept design with regard to the increase in the transport capacity of non fully laden trailers; the stipulated condition that payload remains constant must still be applied. When allowing fully laden 40 tons trailers of 12.2 m length, the number of trailers transported by the design alternatives are approximatley 6% higher than that of the base ship. This is due to the fact that the larger vessels do not require 234 ton of ballast in the fully loaded condition.
Furthermore, when keeping payload constant, the larger design alternatives have relatively enough space available on both D and E decks for the carriage of homogeneous cargo of respectively 191 trailers of 34.6 ton and 233 trailers of 28.3 ton. This is an increase by respectively 22% and 49% compared to the base ship. Based on a single price per trailer, the earning capacity of the larger alternatives will therefore increase with a similar percentage if, and when, the market has lighter trailers on offer.
If only the D and E decks are utilised for the carriage of trailers, loading and discharging times per trailer will be relatively reduced due to the fact that these decks are more easily accessible than the lower F hold.

Table 2
Results of economical calculations

Index	ESC-0	ESC-1	ESC-2
Building costs	1.00	1.10	1.28
Power at 22 knots	1.00	1.05	1.32
Operational costs	1.00	1.08	1.18
Transport efficiency[1]	1.00	1.01	0.80
Transport efficiency[2]	1.00	1.17	1.13
Trailer capacity[1]	1.00	1.06	1.06
Trailer capacity[2]	1.00	1.22	1.49

[1] 12.2 m. trailers total all in load of 40 tons each
[2] idem with all in load of less than 40 tons each

Although not advocated by the authors, if (the lowest) F deck were included within the cargo carrying capacity, space would be available for yet another 28 and 40 trailers for the alternatives. This would result in the carriage of homogeneous cargo of respectively 219 trailers of 30.1 ton 273 trailers 24.2 ton. This is an increase of 40% and 75% respectively, compared to the base ship. The earning capacity of the alternatives will therefore increase with a similar percentage if, and when, the market has lighter trailers on offer and the price per trailer is independent of the mass carried within.

7. CONCLUSIONS

The following conclusions are drawn with regard to the feasibility of the Enlarged Ship Concept applied to a freight carrying vessel (see also table 2):

- The ESC when applied to such large and relatively moderate Froude number vessels appears, at first glance, to be far less viable than for the fast patrol boat. This is mainly due to the relatively larger increase in building and exploitation costs.

- Heave, pitch and related phenomena on the bridge of such a RORO vessel in waves, although not excessive, are sufficiently reduced by the application of ESC.

- Roll motions on the bridge of such a RORO vessel in waves are increased by the application of ESC. However this increase is still acceptable with the criteria applied.

- The vertical midship bending moment in rough weather increases largely for the larger design alternatives; in Beaufort 10 the increase is of the same order as the expected increase of the calm water bending moment which is proportional to the square of the ratio between vesssel length and base ship length.

- In the case of the RORO Freighter/Passenger cargo vessels, a definitive advantage of the ESC is the provision of space for the accommodation of lighter cargoes if available which consequently increase the earning capacity and transport efficiency.

- Applying ESC to a RORO vessel renders an improvement in concept design with regard to a significant improvement in survival capability after having suffered the ingress of water into the hull; the condition that the lowest hold remains empty and optimally subdivided for this purpose must be respected.

8. RECOMMENDATIONS

Further optimisation of the enlarged designs of the RORO freighter/passenger ferry may well lead to more promising results and is recommended as follows:

- Optimise the vertical position of the upper deck of the enlarged vessels in order to reduce the vessel mass, while, at the same time, satisfying the requirements regarding allowable stress values due to longitudinal bending moments.

- Optimise the mass of the enlarged vessels by the utilisation of high tensile steel. This will surely reduce the vessel mass while at the same time being able to withstand the higher longitudinal bending stresses.

- Optimise the vessel form with regard to vessel resistance and propulsion. This can be done by optimisation of the longitudinal centre of buoyancy, ships lines, etc.

- Optimise the vessels turn around time by not utilising the F deck for the carriage of trailers.

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